Final results on $\bar{p}p \to \bar{\Lambda}\Lambda$ Analysis with Extended Target

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Outline

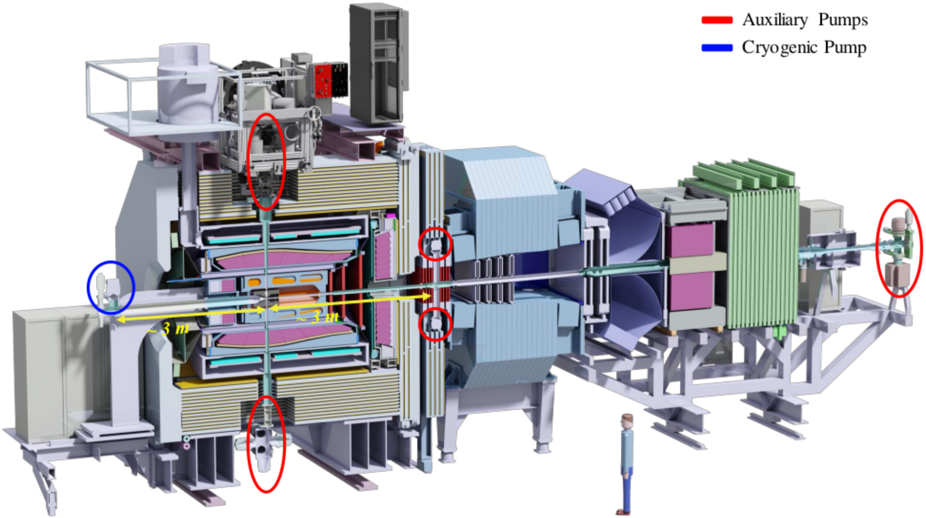
- Motivation
- Vacuum scenarios (extended target)
- Benchmark analysis ($\bar{p}p \to \Lambda\bar{\Lambda} \to \bar{p}\pi^+p\pi^-$)
- Summary of Results
- Outlook

Motivation

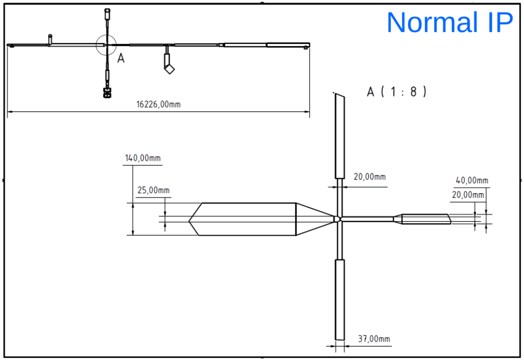
- Presence of residual gas in the beam pipe
  - Effectively larger target
  - Vacuum simulations performed by cluster-jet target group at Münster.
- $\bar{p}p \to \Lambda\bar{\Lambda}$ analysis as benchmark
  - Well studied channel
  - Displaced vertices, special for background suppression
  - Expertise at Uppsala

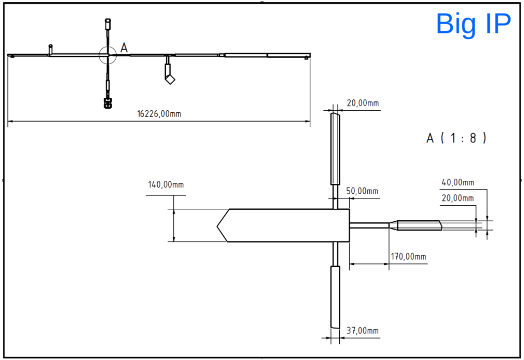
- $\bar{p}p \to \Lambda\bar{\Lambda}$ analysis for extended target.

Location of Vacuum Pumps



IP Configurations





NOTE: BigIP has been dropped due to *(i)* results not significantly different from NormalIP, *(ii)* requires changes in MVD due to larger scattering matrix.

Vacuum Studies

Four different scenarios have been studied [A. Khoukaz (CM 20/1)]

- NormalIP[1]
- NormalIP + Cryo Pumps
- BigIP[2]
- BigIP + Cryo Pumps

(+) Four **extended target** profiles are provided by Münster group (April 21, 2021).

[1] original IP geometry with 140mm upstream beam pipe
[2] proposed IP geometry with large scattering chamber

Benchmark Analysis

The exclusive $\bar{p}p \to \Lambda\bar{\Lambda} \to \bar{p}\pi^{+}p\pi^{-}$ analysis as a benchmark

- Point-like target
- 10^6 events at 1.642 GeV/c
- EvtGen as simulator (Signal and Non-resonant Bkg.)
- Ideal Reco and Ideal PID algorithms
- Event selection is based on Walter's Ph.D. thesis

Replicate $\bar{p}p \to \Lambda\bar{\Lambda}$ analysis for

- Extended target

(+) Software stack includes FairSoft (nov20), FairRoot (18.6.1) & PandaRoot (12.0.1)

Simulated Samples

$$w_{\text{bkg.}} = \frac{N_{\text{signal}}}{N_{\text{background}}} \cdot \frac{\sigma(\bar{p}p \to \bar{p}\pi^+ p\pi^-)}{\sigma(p\bar{p} \to \Lambda\bar{\Lambda}) \cdot BR(\Lambda \to p\pi)^2}$$

Channel	$\bar{p}p \to \bar{\Lambda}\Lambda \to \bar{p}\pi^+ p\pi^-$	$\bar{p}p \to \bar{p}\pi^+ p\pi^-$
Sample	10^6	10^6
Cross section [μb]	64	15.4
Weighting factor	1	0.589

Note: Weights are applied whenever signal & background samples are compared.

Figure of Merit (FoM)

The figure-of-merit (FoM) is the expected ratio of events from the signal and the non-resonant background weighted with ratios of respective cross-sections:

$$FoM = \frac{\epsilon(p\bar{p} \to \Lambda\bar{\Lambda})}{\epsilon(p\bar{p} \to \bar{p}\pi^{+}p\pi^{-})} \cdot \frac{\sigma(p\bar{p} \to \Lambda\bar{\Lambda}) \cdot BR(\Lambda \to p\pi^{-})^{2}}{\sigma(p\bar{p} \to \bar{p}\pi^{+}p\pi^{-})}$$

where ϵ is the efficiency for a given channel, $\sigma(p\bar{p} \to \Lambda\bar{\Lambda}) = 64.1 \pm 0.4 \pm 1.6\ \mu b$, $BR(\Lambda \to p\pi^{-}) = 63.9 \pm 0.5\%$ and $\sigma(p\bar{p} \to \bar{p}\pi^{+}p\pi^{-}) = 15.4 \pm 5.2\ \mu b$.

Pre-selection Criteria

The following pre-selection criteria is used:

- Events with at least 4 charged tracks
- All possible combinations of $p\pi^-$ and $\bar{p}\pi^+$ are considered.
- Invariant mass of $p\pi^-$ fulfills $|m(\Lambda) - m(p\pi^-)| < 0.3\ \mathrm{GeV}/c^2 + \mathrm{c.c.}$
- Vertex fit on all $\Lambda, \bar{\Lambda}$ candidates, reject those with $prob < 0.01$.
- For multiple $\Lambda/\bar{\Lambda}$ candidates, keep those with smallest χ^2 value.
- $\Lambda, \bar{\Lambda}$ candidates are combined to reconstruct the $p\bar{p}$ system.
- A successful 4C-fit is required to reconstruct $\bar{p}p$.

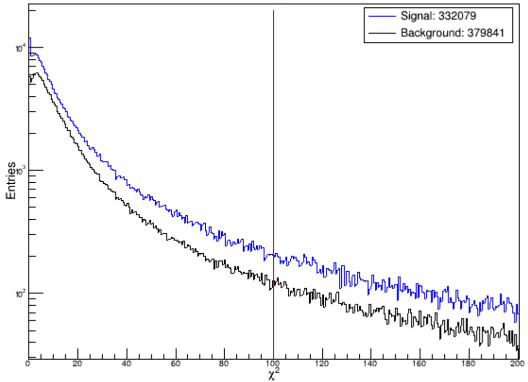
After pre-selection, at-most one $\Lambda\bar{\Lambda}$ pair exists per event.

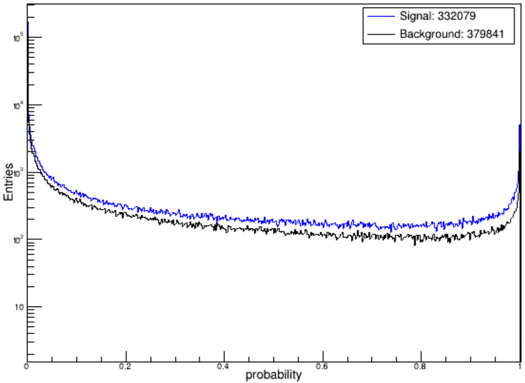
Final Selection Criteria

The following final selection is used:

- 4C fit quality:
  - $\chi^2_{4C} < 100$
- Mass criteria:
  - $|m_{fit}(p\pi^-) - m_{PDG}(p\pi^-)| < 5 \cdot \sigma_{m_{fit}}(p\pi^-)$ GeV/c^2
  - $|m_{fit}(\bar{p}\pi^+) - m_{PDG}(\bar{p}\pi^+)| < 5 \cdot \sigma_{m_{fit}}(\bar{p}\pi^+)$ GeV/c^2
- The z distance from IP (displaced decay vertex)
  - $z_{fit}(\Lambda) + z_{fit}(\bar{\Lambda}) > 2$ cm

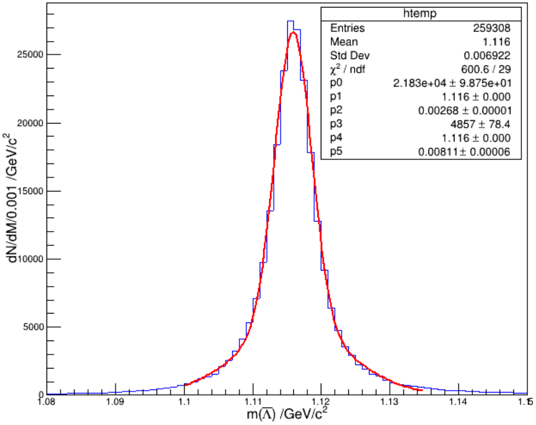
Final Selection: $\chi^2_{4c} < 100$

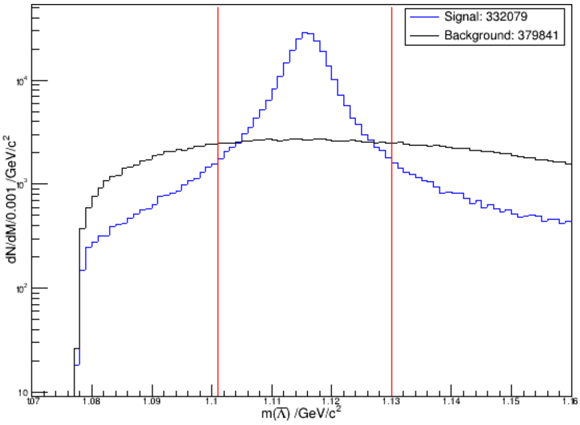




χ^2 cut removes $\sim 22\%$ events in addition to pre-selection.

Final Selection: Mass cut on $m(\bar{p}\pi^+)$

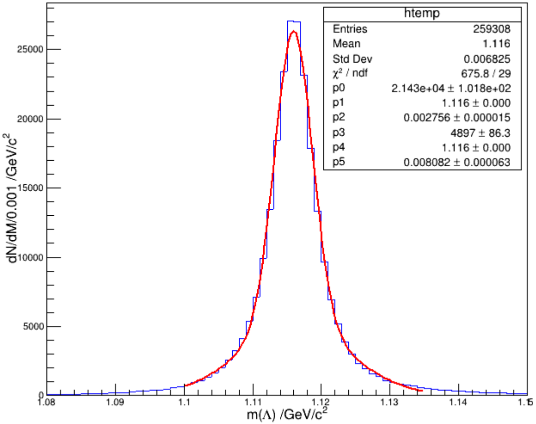


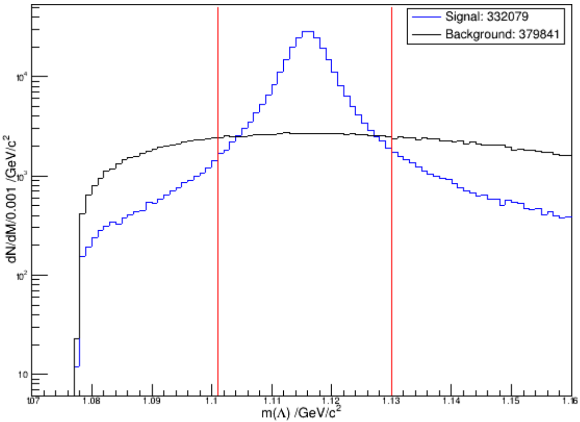


Double Gaussian fit is used to obtained the mass resolution:

$\Rightarrow \sigma_{m_{fit}}(\bar{p}\pi^+) = 2.680 \cdot 10^{-3}$ GeV/c^2

Final Selection: Mass cut on $m(p\pi^-)$



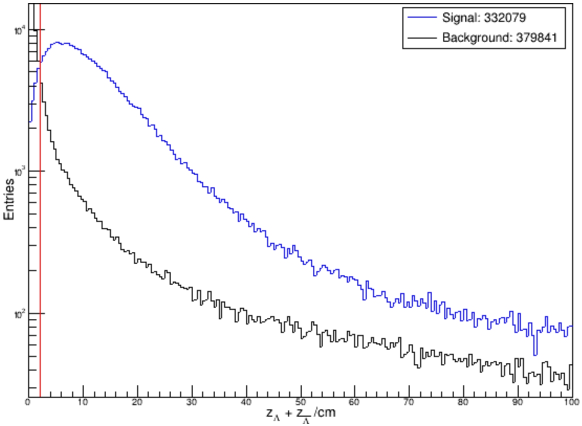


Double Gaussian fit is used to obtained the mass resolution:

$\Rightarrow \sigma_{m_{fit}}(p\pi^-) = 2.756 \cdot 10^{-3}$ GeV/c^2

Final Selection: $z_{\bar{\Lambda}} + z_{\Lambda} > 2$ cm

- Decay vertex cut has significant impact on background suppression.
- Suppression power of this cut will be different for various target profiles.
- One can optimize this cut for different targets which will increase the efficiency.

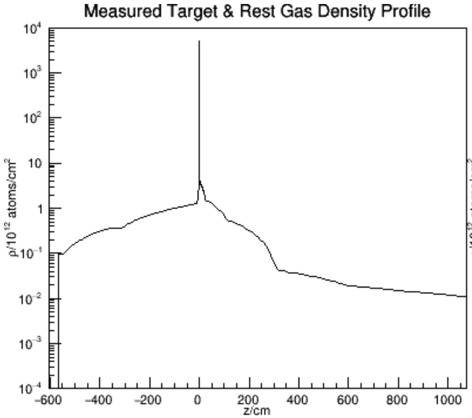


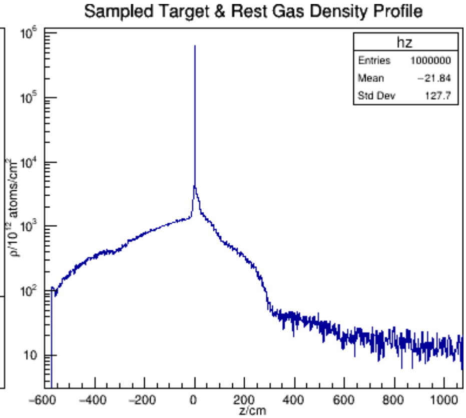
Final Efficiency: Point-like Target

Channel	$p\bar{p} \to \bar{\Lambda}\Lambda \to \bar{p}\pi^+ p\pi^-$	$p\bar{p} \to \bar{p}\pi^+ p\pi^-$
Generated	10^6	10^6
Pre-selection	332079	379841
$\chi^2 < 100$	259308	307342
Mass cut	222344	28787.0
$z_{\bar{\Lambda}} + z_{\Lambda} > 2$ cm	200772	3443.00
Efficiency %	20.1 ± 0.05	0.34 ± 0.006

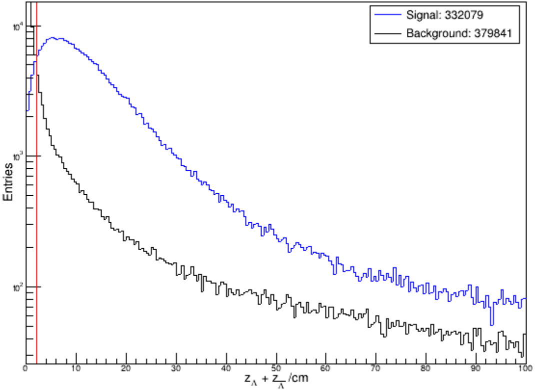
$$FoM = 99$$

Density Profile: Extended Target (NormalIP)

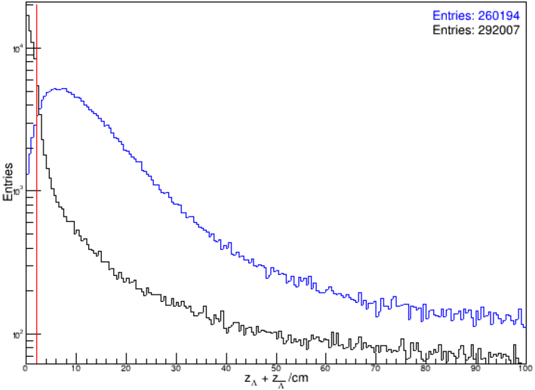




Decay Vertex Cut: Point-like v.s. NormalIP



(a) Point-like



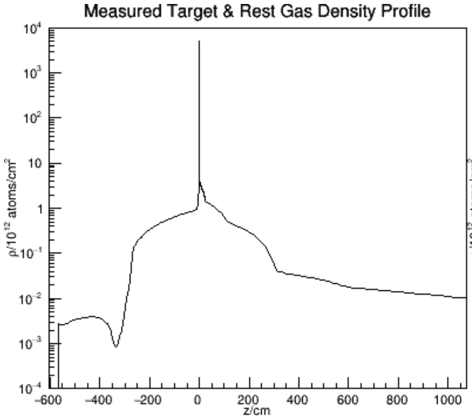
(b) NormalIP

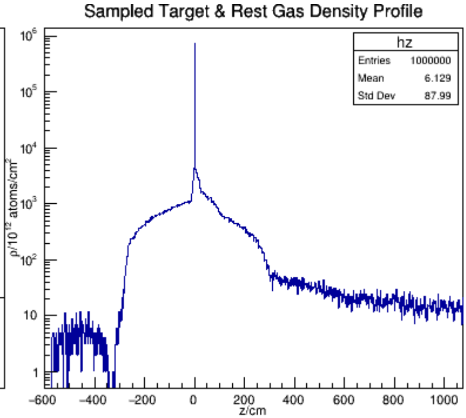
Final Efficiency: Extended Target (NormalIP)

Channel	$p\bar{p} \to \bar{\Lambda}\Lambda \to \bar{p}\pi^+ p\pi^-$	$p\bar{p} \to \bar{p}\pi^+ p\pi^-$
Generated	10^6	10^6
Pre-selection	260194	292007
$\chi^2 < 100$	205461	238505
Mass cut	175180	23722.0
$z_{\bar{\Lambda}} + z_{\Lambda} > 2$	155239	5929.00
Efficiency %	15.5 ± 0.04	0.59 ± 0.008

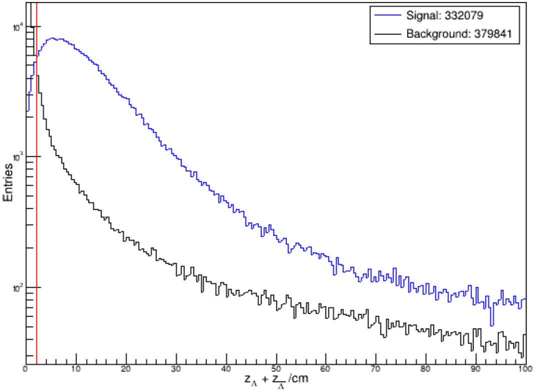
$$FoM_{ext.,1} = 42$$

Density Profile: Extended Target (NormalIP+Cryo)

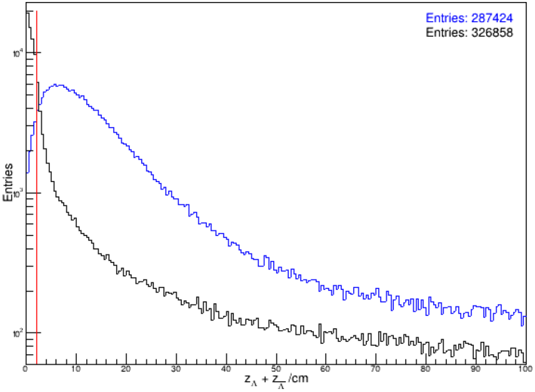




Decay Vertex Cut: Point-like v.s. NormalIP+Cryo



(a) Point-like



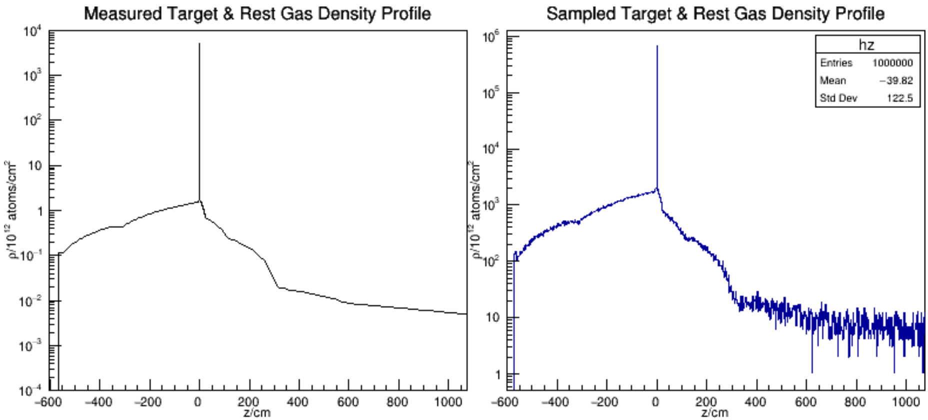
(b) NormalIP+Cryo

Final Efficiency: Extended Target (NormalIP+Cryo)

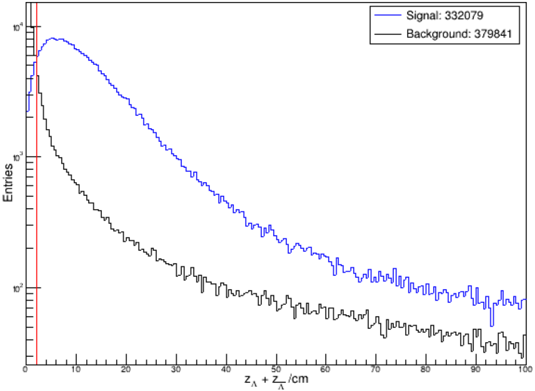
Channel	$p\bar{p} \to \bar{\Lambda}\Lambda \to \bar{p}\pi^+ p\pi^-$	$p\bar{p} \to \bar{p}\pi^+ p\pi^-$
Generated	10^6	10^6
Pre-selection	287424	326858
$\chi^2 < 100$	227306	266872
Mass cut	193980	26611.0
$z_{\bar{\Lambda}} + z_{\Lambda} > 2$	173597	6503.00
Efficiency %	17.4 ± 0.04	0.65 ± 0.008

$$FoM_{ext.,2} = 45$$

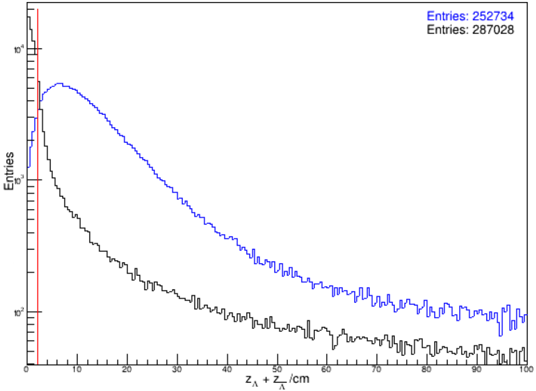
Density Profile: Extended Target (BigIP)



Decay Vertex Cut: Point-like v.s. BigIP



(a) Point-like



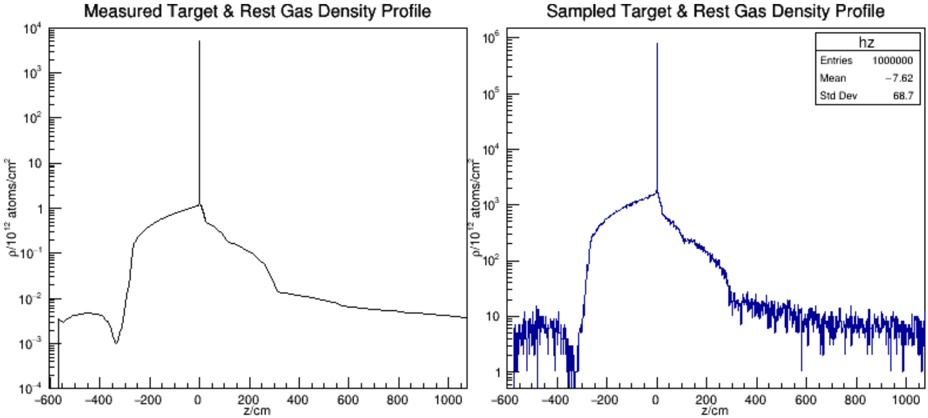
(b) BigIP

Final Efficiency: Extended Target (BigIP)

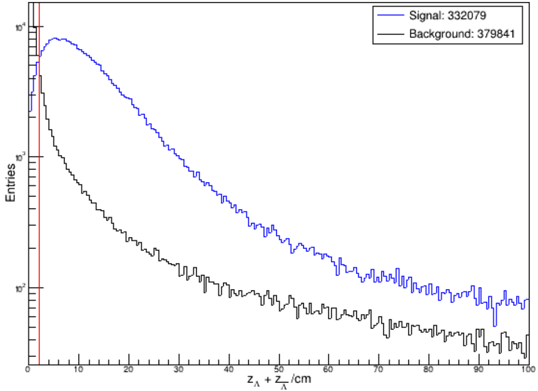
Channel	$p\bar{p} \to \bar{\Lambda}\Lambda \to \bar{p}\pi^+ p\pi^-$	$p\bar{p} \to \bar{p}\pi^+ p\pi^-$
Generated	10^6	10^6
Pre-selection	252734	287028
$\chi^2 < 100$	198170	233143
Mass cut	168824	22974.0
$z_{\bar{\Lambda}} + z_{\Lambda} > 2$	147868	4662.00
Efficiency %	14.8 ± 0.04	0.47 ± 0.007

$$FoM_{ext.,3} = 54$$

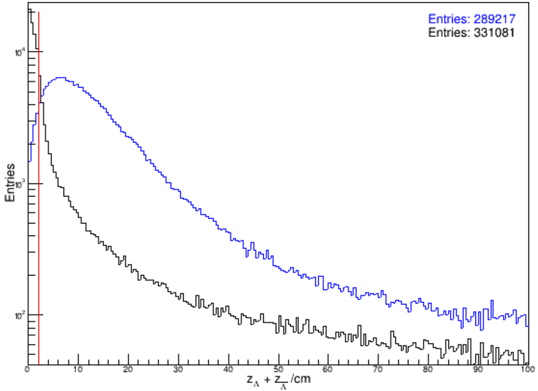
Density Profile: Extended Target (BigIP+Cryo)



Decay Vertex Cut: Point-like v.s. BigIP+Cryo



(a) Point-like



(b) BigIP+Cryo

Final Efficiency: Extended Target (BigIP+Cryo)

Channel	$p\bar{p} \to \bar{\Lambda}\Lambda \to \bar{p}\pi^+ p\pi^-$	$p\bar{p} \to \bar{p}\pi^+ p\pi^-$
Generated	10^6	10^6
Pre-selection	289217	331081
$\chi^2 < 100$	226578	268365
Mass cut	193307	26755.0
$z_{\bar{\Lambda}} + z_{\Lambda} > 2$	171472	5086.00
Efficiency %	17.1 ± 0.04	0.51 ± 0.007

$$FoM_{ext.,4} = 57$$

Summary

Target	ϵ_{sig} [%]	ϵ_{bkg} [%]	FoM
Point-like	20.1 ± 0.05	0.34 ± 0.006	99
NormalIP	15.5 ± 0.04	0.59 ± 0.008	44
NormalIP+Cryo	17.4 ± 0.04	0.65 ± 0.008	45
BigIP	14.8 ± 0.04	0.47 ± 0.007	54
BigIP+Cryo	17.1 ± 0.04	0.51 ± 0.007	57

- Optimizing the decay vertex cut will slightly increase the FoM for extended cases. Their relative mutual difference might not change significantly.
- Significant difference between point-like & extended cases which can't be ignored.
- The difference between BigIP and NormalIP seems not catastrophic. However, there is reasonable increase in FoM from NormalIP (+Cryo) to BigIP (+Cryo) configurations.

Outlook

- Updated IP configuration (alternative to BigIP) will be analyzed
- Decay vertex cut can be optimized for extended target cases.
- An release note will be submitted soon on these results.
- The results will be presented in upcoming Nordic Physics Days 2021.

Questions?

Backup Slides